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Contextual Interference in Speech Motor Learning Secondary to Similar Phonemes

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Abstract

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Purpose: The contextual interference (CI) effect is a motor learning phenomenon where learners experience difficulty during training resulting in poor performance; however, improved performance is observed in transfer conditions. Different variables elicit a CI effect, and the purpose of this study is to investigate whether phoneme (or sound) similarity may result in a CI effect during speech motor learning.

Method: The study included twenty-nine participants whose hearing and speech abilities were within the normal range. Participants were randomly assigned to one of two training sessions involving nonwords with either similar or dissimilar phonemes. Each training session included nonword repetition training with feedback, retention task where trained nonwords were repeated without feedback, and a transfer task where novel, untrained nonwords were repeated. Following the first training session, participants initiated the second training session with the opposite set of stimuli. Stimuli assignment was counterbalanced across participants. Analyses include perceptually rating accuracy of the nonword productions.

Results: Results suggest motor learning is influenced by the number of similar phonemes present in each nonword. This is suggestive of a CI effect due to phoneme similarity. Nonwords containing both similar and dissimilar phonemes initiated a learning effect. Additionally, training with dissimilar phonemes demonstrated the presence of a CI effect.

Conclusion: Training with dissimilar phonemes does initiate a CI effect, which should allow phonemic similarity to be considered a more prominent CI variable in motor learning. Clinicians should manipulate their target words to contain more dissimilar phonemes, induce the CI effect, and improve clinical outcomes.

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Introduction

In speech-language pathology, clinicians remedy speech disorders by helping clients learn new motor patterns. During therapy, clients repeat sounds (e.g., phonemes) and are provided feedback on their accuracy from clinicians. Imagine a patient cannot pronounce “pah” (i.e., /p/) at the beginning of words. First, the clinician would attempt to rebuild the motor pattern by repeating the sound in the beginning of a word. Multiple repetitions are produced with feedback throughout this training stage of motor learning (Schmidt and Lee, 2005). Once a client has achieved a high level of accuracy during training, the clinician aims to solidify the motor pattern in long-term memory (Schmidt and Lee, 2005). Continued repetitions of /p/ may occur without feedback to assess the client’s motor plan during a retention phase of motor learning (Schmidt and Lee, 2005). Lastly, we would modify the activity to transfer the sound to real life use, which is termed the transfer stage of motor learning (Druckman and Bjork, 1994). The client needs to be able to produce the sound within various contexts (e.g., multiple words) aside from the original activities used in therapy (Schmidt and Lee, 2005). These stages of motor learning are assumed to promote success, or transfer, in using the targeted motor pattern (e.g., /p/) in trained and untrained contexts (e.g., words and sentences) (Schimdt and Lee, 2005).

The progression of each stage of motor learning, from training to retention and finally transfer, should result in successful, skilled movements. Other factors, such as similarity of the motor patterns, may also have an effect on motor learning. Previously, researchers expected to see subjects learn more without variation because of repetitive motor patterns (Lee, Wulf, and Schmidt, 1992). However, we often see patients struggling to transfer their skills when training with similar movements, which results in an overall negative learning outcome (Lee, Wulf, and Schmidt, 1992). Furthermore, it is not uncommon to observe great learning outcomes during the transfer stage when clients struggled with differentiated movement patterns, which must be reconstructed, during the training and retention stages of motor learning (Lee, Wulf, and Schmidt, 1992). This contradictory phenomenon is known as the contextual interference (CI) effect (Lee, Wulf, and Schmidt, 1992). Several variables, aside from practice schedule, induce a CI effect, including the similarity of training items to one another. However, defining similarity is difficult and the match between two motor tasks may be related to the environmental, social, or psychological properties of the movement (Gick and Holyoak, 1987).

In this study, we investigated the CI effect in speech motor learning by experimentally manipulating similarity of nonwords. To fully understand the influence of the CI effect in speech production, a literature review will be presented. First, the three stages of motor learning will be reviewed: training, retention, and transfer (Schmidt and Lee, 2005). Second, a historical review of the CI effect will be provided and related the construct of similarity. Finally, similarity will be defined in terms of speech production.

Motor Learning:

As noted earlier, there are three separate stages of motor learning. The first stage of motor learning is the training stage (Schmidt and Lee, 2005). Training refers to the actions a participant has to take to learn the information and commit the information to memory (Schmidt and Lee, 2005). Training often requires practicing a movement pattern for a large number of trials while receiving feedback regarding performance (Schmidt and Lee, 2005). Different variables of training have been documented to change learning outcomes. For example, training schedule can be organized in a blocked order (where all movements are presented in the same order) or in a randomized order (where all movements are presented randomly to the learner; (Schmidt and Lee, 2005). Training schedule is just one of many variables that influence motor performance. Indeed, much of the motor learning literature has focused on evaluating motor variables during training in an effort to obtain the best motor outcomes (Schmidt and Lee, 2005).

The second stage of motor learning is the retention stage. “Retention refers to the persistence or lack of persistence of the performance” (Schmidt and Lee, 2005, p. 434). After the participant is trained, the information must be retained and moved from short-term to long-term memory (Kantak & Weinstein, 2012). Retention can be evaluated in a single session (short-term retention) or across multiple sessions (long-term retention; Kantak & Weinstein, 2012; Battig, 1979). Typically, feedback is removed during retention to assess stability and accuracy of the movement pattern.

The third stage of motor learning is the transfer stage. During the transfer stage of learning, individuals use a previously learned motor skill to complete other motor tasks (Gick and Holyoak, 1987). Generally, transfer assumes a trained motor plan provides guidance on untrained movements. This has been termed positive transfer, which encourages learning based on a previous task (Gick and Holyoak, 1987). Transfer does not have to be measured after a single event and can be measured over a period of time (Gick & Holyoak, 1987). Historically, positive transfer has been associated with motor tasks that are similar to one another.

Contextual Interference:

In terms of motor learning, there are training conditions that can facilitate or detract from motor learning. One example of this is training or practice schedule. Training schedules dictate what order stimuli are presented or in what order a movement is practiced (Schmidt and Lee, 2005). Blocked practice requires the learner to perform the same movement patterns until a level of success is met prior to moving onto a new movement pattern (Schmidt and Lee, 2005). Random practice, conversely, requires the learner to practice all movement patterns during training without a specific order (Schmidt and Lee, 2005). Training conditions, such as training schedule, can influence each stage of the motor learning process. Specifically, learners have increased accuracy in performing movements during blocked practice conditions and low accuracy during random practice. However, when evaluating transfer (or generalization) to new movement patterns, learners have better transfer under random practice conditions (Schmidt and Lee, 2005) This is an example of the CI effect, a phenomenon where increased difficulty during the training stage of learning results in increased learning in the retention and transfer stages (Druckman and Bjork, 1994).

Practice schedule is one of the most researched variables of the CI effect in motor learning (e.g., Ballard et al., 2015; Maas et al., 2008). However, other variables such as similarity between tasks, have been observed to induce the CI effect. Historically, similarity was one of the first variables used to demonstrate the CI effect while learning words (Battig, 1979 per Timothy D. Lee et al., 1992). Within the motor learning literature, the construct of similarity is thought to be important for transfer (Lee, Wulf, and Schmidt, 1992). However, defining similarity has remained a challenge. Similarity has been defined as the physical properties shared between two motor tasks or the same learning environments (e.g., Landin et al., 2003; Simon & Bjork, 2002; Tremblay, Houle, & Ostry, 2008). Similarity has also been defined as the underlying cognitive processes used to generate movements (Baddeley, 1979; Horak, 1992).

Similarity in the realm of speech has been limited. Thus, in order to use similarity as a measure for evaluation, we must figure out how to define similarity within speech. Physically, similarity is typically defined by movement patterns that are nearly identical. In speech, comparison of movement patterns of the articulators (e.g., tongue, lips jaw) would be assessed.

Similarity could be defined by the repetition of the same movement patterns of the articulators. However, speech is unique compared to the limbs. We use speech to express language, which consists of various sounds (phonemes), sound combinations (morphemes), etc. Thus, both movement patterns and linguistic components must be considered when inducing a CI effect during speech learning. Does the CI effect occur with similar movement patterns, as observed with motor learning in the limbs, or with linguistic variables that are specific to speech? In the past, only practice schedule has been evaluated as a CI variable within motor learning. In this study, we attempt a new approach by using a variable of phonetic similarity to induce the CI effect.

In this study, we manipulated two sets of stimuli, one containing similar phonemes and another set of stimuli with dissimilar phonemes, to observe whether phoneme similarity influenced motor learning. Participants were challenged to repeat nonwords for one set of stimuli for each of stage of motor learning. They began with the training stage that includes feedback, continued with the retention phase without feedback, and, lastly, they concluded with the transfer phase that consisted of completely new nonwords. Once one set of stimuli was completed (e.g., nonwords with similar phonemes), the second set of stimuli was started using the same procedure (e.g., nonwords with dissimilar phonemes). Evaluation of participant's productions based on their ability produce each phoneme correctly (percent phonemes correct, PPC) was assessed at the end of training and during the transfer task. This study predicts a CI effect when participants train with the nonwords containing dissimilar phonemes (Figure 1).

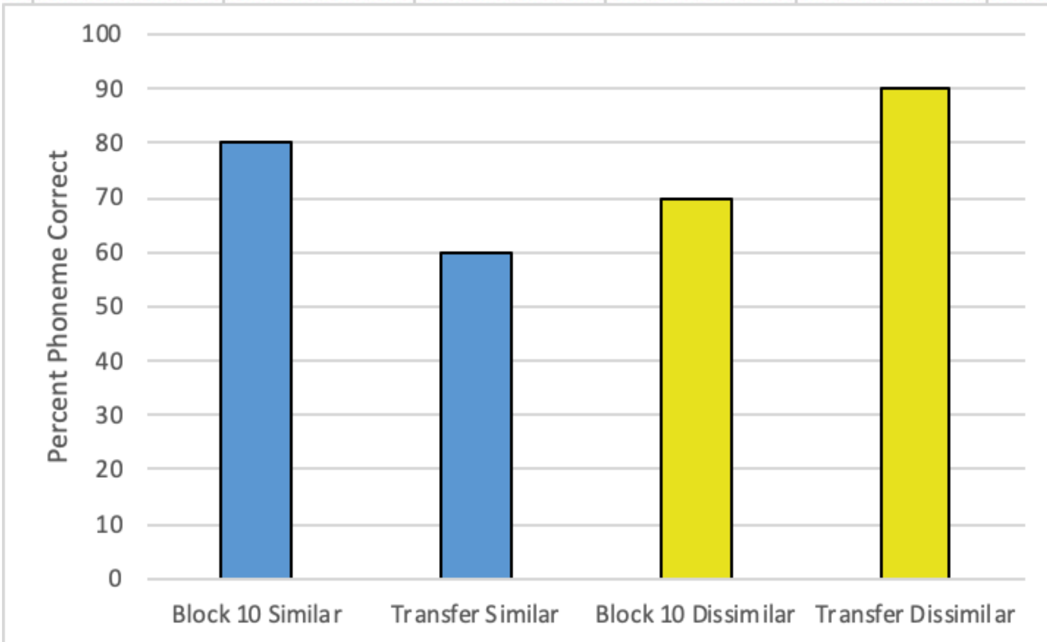

Figure 1: Proposed contextual interference effect based on phoneme similarity

Methods

Participants:

We used previously collected data from twenty-nine participants from 18 to 35 years of age. Participants were fluent native English speakers without proficiency in other languages and were required to have a minimum of a high school diploma (or the equivalent). Participants were also required to have normal oral mobility including tongue, lips, and mandible range of motion. The Test of Minimal Articulation, including its sentence and reading screening subtests (Secord, 1981), were administered to participants in order to avoid speech disorders. Lastly, participants tested their working memory using the Memory for Digit and Nonword Repetition subtests from the Comprehensive Test of Phonological Processing – 2nd edition (Wagner, Torgesen, Rashotte, & Pearson, 2013). Participants must achieve minimum raw scores on the test to be eligible for the study.

Participants were recruited through the placement of IRB-approved fliers across West Virginia University's campus. IRB-approved advertisments were displayed to the Facebook page off the Speech Motor Control Lab. Participants were also recruited through IRB-approved e-mail blasts sent from West Virginia University colleges (e.g., College of Education and Human Services). Recruitment also took place through the West Virginia University psychology pool (SONA) following approval by the Psychology deparment. Procedures throughout this experiment were conducted in the WVU Speech Motor Control Laboratory by a trained IRB-investigator.

Interested participants contacted the Speech Motor Control lab, and they were administered a pre-screening language questionaire. Participants who did not meet this criteria were dismissed from the study, while those who passed moved on to the experimental session. Written consent was obtained during each experimental session. The consent form aligned with policies introduced by the West Virginia University Institutional Review Board. Following consent, participants proceeded to a screening procedure to ensure they were eligible. These procedures lasted less than 30 minutes. If the study was completed and the particpant passed their screening, they were compensated with a $15 gift card.

Stimuli:

A total of 40 stimuli divided into two categories, similar and dissimilar, were used from Meigh (2017). All stimuli were three syllables (CV|CV|CVC) with stress placed on either the first or second syllable. Of the seven phonemes in each word, all had low-frequency biphone probabilities. Each set of stimuli (i.e., similar and dissimilar) were further divided into ten training nonwords and ten transfer nonwords per set. A full list of stimuli is presented in Appendix A.

As noted in Table 1, stimuli were defined as "similar" and "dissimilar" to one another based on the average number of different phonemes within a word, vowel placement, phonotactic probabilities, and intraword similarity. The average number of different phonemes was calculated by counting each phoneme within a word without counting repetitions. Then, the average was taken for each category. Vowels within each word were examined for differences such as high vs. low, front vs. lax, and tense vs. lax, and central location. Average phonotactic probability was analyzed at both the position-specific and biphone level. The position-specific information presents how often a given phoneme appears in that certain position in all words of the English language. Biphone levels are used to analyze two adjacent phonemes within a word. Intraword similarity evaluates how many vowels or consonants are shared between two words. This total was also averaged for each word in a given category (e.g. Similar Training).

Table 1: Stimuli characteristics

	Similar Training	Dissimilar Training	Transfer Similar	Transfer Dissimilar
Stimuli Example	/tenærok/	/fozæʃɔd/	/raθʌsæθ/	/gigʊðib/
Number of different phonemes	19	28	13	28
Average phonotatic probabilities: Position-Specific	1.25	1.17	1.21	1.18
Average phonotatic probabilities: Biphone	1.11	1	1.01	1
Intraword Similarity: Consonants	4	0	8	8
Intraword Similarity: Vowels	8	4	0	4
Vowel: High vs. Low	2 high, 3 low	6 high, 3 low	0 high, 3 low	6 high, 3 low
Vowel: Front vs. Back	2 front, 3 back	5 front, 4 back	1 front, 2 back	4 front, 5 back
Vowel: Tense vs. Lax	4 tense, 2 lax	6 tense, 4 lack	2 tense, 3 lax	6 tense, 5 lax
Vowel: Central	1	1	2	2

Experimental Setup:

Following methods used in Kee (2018), participants were fitted with a dynamic headset unidirectional microphone (SHURE WH20XLR) relatively one-inch mouth-to-microphone distance. Approximately 6 inches from the participant, a digital voice recorder (Olympus DM-901) was attached to the microphone to record each task. Experimental software, E-Prime, was run on a 64-bit Dell Latitude 3340 laptop with Windows 7 operating system. To ensure the participant could hear the stimuli, stereo speakers (Bose Companion 2 Series 3) were roughly 15 inches in front of the participant.

Experimental Procedure:

During a single session, participants participated in two nonword repetition tasks. Each nonword repetition task consisted of three phases: training, retention, and transfer phase. During each phase, participants would repeat either similar or dissimilar stimuli. These stimuli sets were never presented together to participants. By the end of the experiment, each participant would have participated in a similar training, retention, and transfer, as well as a dissimilar training, retention, and transfer phase of the experiment. Each stimuli set was counterbalanced across participants (Table 2). Each phase of training will be detailed below.

Table 2: Counterbalancing across all experimental tasks.

Subjects	Training 1	Generalization 1		Training 2	Generalization 2	
Ss 1	Similar-Trained	Similar Retention #1	Similar Transfer #1	Dissimilar-Trained	Dissimilar Retention #1	Dissimilar Transfer #1
Ss 2	Similar-Trained	Similar Retention #2	Similar Transfer #2	Dissimilar-Trained	Dissimilar Retention #2	Dissimilar Transfer #2
Ss 3	Dissimilar-Trained	Dissimilar Retention #1	Dissimilar Transfer #1	Similar-Trained	Similar Retention #1	Similar Transfer #1
Ss 4	Dissimilar-Trained	Dissimilar Retention #2	Dissimilar Transfer #2	Similar-Trained	Similar Retention #2	Similar Transfer #2

Nonword Repetition Training: During this phase, participants were presented with an auditory presentation of a nonword, which they repeated into the headset microphone. Participants were randomly assigned to start training with either similar or dissimilar training stimuli. Each nonword was presented over the course of 10 blocks, resulting in 100 repetitions of each nonword. During training, the examiner noted incorrect productions by pushing a button on the computer. Following each training block, Eprime replayed misarticulated training nonwords for the participant. No other feedback was provided during training.

Nonword Retention: Following ten blocks of training, participants repeated the training nonwords without feedback in a single retention block. To avoid order effects, two retention blocks of stimuli were created for each set of stimuli (similar and dissimilar) and these blocks were counterbalanced across participants (Figure 2).

Nonword Transfer: After the retention phase, participants repeated new nonwords not encountered during training or retention in a single transfer block. Two transfer blocks of stimuli were created for each set of stimuli (similar and dissimilar) and these blocks were counterbalanced across participants.

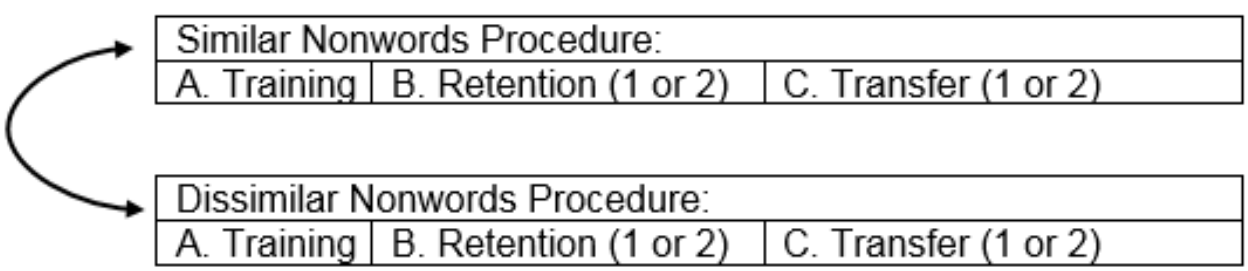

Figure 2: Example of counterbalancing within each procedure

Measurements and Data Preparation:

Nonwords from the training, retention, and transfer tasks were individually scored for phoneme accuracy by two blinded listeners trained in phonetic transcription. Accurate phoneme productions were considered correct only if distortions, substitutions, omissions, and insertions were not present. A third, blinded rater resolved any discrepancies in accuracy ratings. Accuracy scores were calculated as percent phonemes correct (PPC). This measure was calculated by dividing the total number of correct phoneme productions from the total number of phonemes in a given nonword. A PPC value was generated for training block 1, training block 10, retention, and transfer trials for each type of stimuli (similar and dissimilar). All PPC values were averaged separately for each participant and these values were then averaged across subject.

Statistical Analysis:

Data for twenty-three participants were analyzed for this study. Repeated measures statistics were used to evaluate the two hypothesized questions: 1) Did the participants learn during training (comparison of PPC values for training blocks 1 and 10)? 2) Was there a CI effect (comparison of training blocks 10 and transfer)? Both questions were answered by conducting separate one-way ANOVAs to evaluate PPC scores. A priori contrasts were conducted to evaluate differences between training blocks 1 and 10 in similar versus dissimilar stimuli. Pairwise comparisons were performed on block 10 and transfer similar versus dissimilar stimuli using a Bonferroni correction for multiple comparisons.

Results

Participant attrition was secondary to three participants failing one or more portions of the screening procedure, equipment failure during one participant's session, and an absence of learning during training for two participants based on visual inspection of each participants' nonword accuracy within each training block. Prior to examining a CI effect, evaluation of learning the similar and dissimilar stimuli was conducted. As noted in Figure 3, participants PPC values increased from block 1 to block 10 for both types of stimuli.

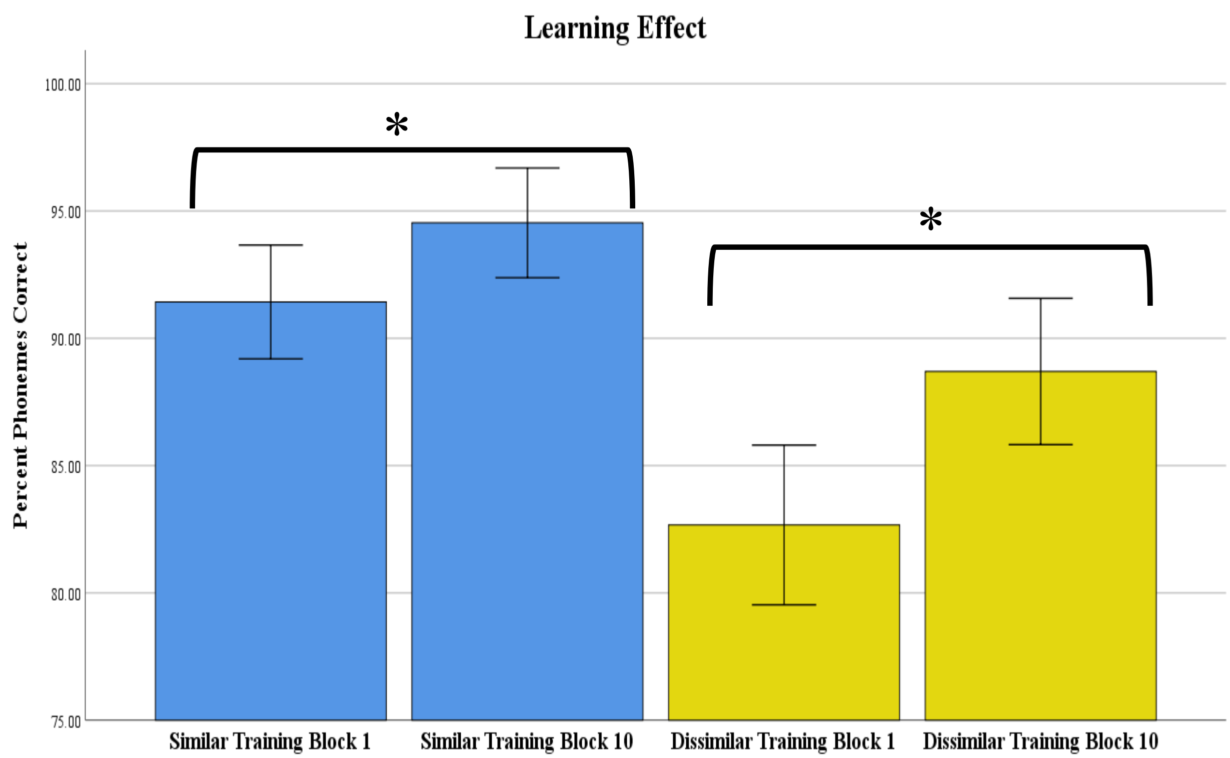

Figure 3: Learning Effect

Note 1: F(1, 21) = 20.495, p < .0001, $\eta_p^2 = .501$
*Note 2: Bars and * indicate significant differences between stimuli sets*
Note 3: Error bars: 95% CI

Examination of the end of training (block 10) to transfer performance revealed a CI effect. Overall PPC scores for similar training stimuli were high at the end of training but decreased significantly when new similar stimuli were introduced. PPC values for dissimilar stimuli were significantly lower than similar stimuli at the end of training; however, PPC scores when producing dissimilar stimuli were significantly higher during transfer (Figure 4).

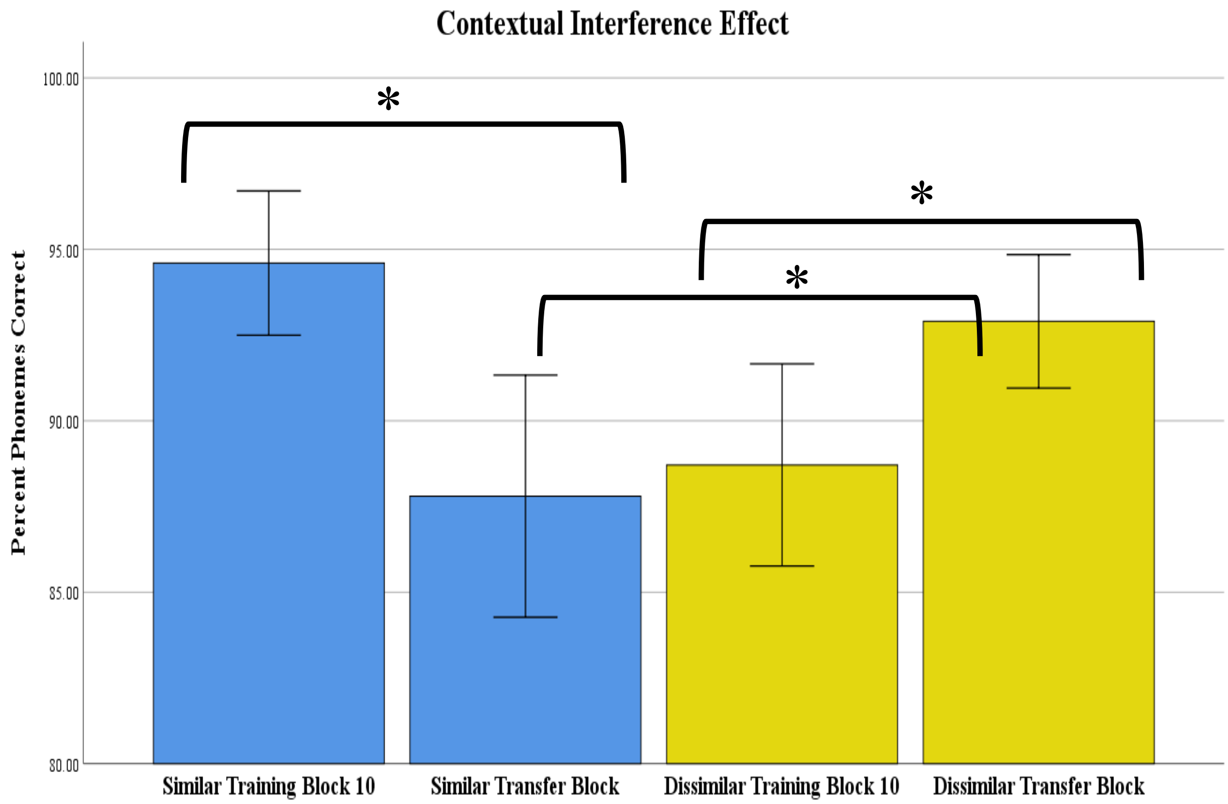

Figure 4: CI Effect

Note 1: F(3,66) = 46.069, p < .0001, $\eta_p^2 = .677$
*Note 2: Bars and * indicate three main significant differences between stimuli sets*
Note 3: Error bars: 95% CI

Discussion

This study was conducted to evaluate the effect of phoneme similarity on producing a CI effect during speech motor learning. Participants practiced producing nonwords and then completed retention and transfer tasks. This procedure was completed twice by each participant with both sets of stimuli (nonwords with either similar or dissimilar phonemes). Results revealed a learning effect with both sets of stimuli. In addition, a CI effect was observed where practice on nonwords with dissimilar phonemes resulted in poor training performance compared to nonwords with similar phonemes. However, overall transfer performance was significantly greater with novel nonwords with dissimilar phonemes. The results of this study suggest that similarity may not always produce greater learning results in speech motor learning. Indeed, the more interference created during training with dissimilar phonemes, the overall better learning outcome achieved with novel nonwords. Additionally, the results of this study suggest linguistic aspects of speech may be useful parameters to manipulate during speech training to achieve better learning outcomes.

There are several limitations with this study. First, the stimuli within this study were borrowed from a previous study. Although the stimuli were analyzed to ensure phonemic differences (see Table 1), creating stimuli for the purposes of this study would have been beneficial. Furthermore, each set of stimuli only contained 10 nonwords. If we would have been able to create new sets of stimuli for both similar and dissimilar nonwords, we could have included more trials to validate the results. In future studies, replication of the procedure may also want to manipulate the other properties of phonemes, e.g., voicing, to evaluate the effects on speech learning.

A second possible limitation in this study was the use of short-term transfer. In our study, each stage of motor learning was completed within a single day. Traditionally, the transformation from short-term memory to long-term memory can take anywhere from hours to weeks (e.g., Battig, 1979; Schmidt & Lee, 2005). However, this procedure used a short-term retention task that was completed within hours. Although learning and CI effects were observed with a short-term transfer period, future studies should be designed across multiple days to evaluate whether these effects change with long-term transfer periods.

In summary, the results of this study suggest that phonemic similarity may influence overall speech motor learning when dissimilar phonemes are practiced. In the future, the results of this study may impact on how we think about speech motor learning in therapeutic settings. For example, clinicians could create stimuli with dissimilar phonemes to use during speech training. The overall goal would be to induce a CI effect and improve overall speech outcomes. If clinicians incorporate more dissimilar stimuli within their target words, it is possible that we may see improved client learning within our clients due to the CI effect.

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Appendix A: Stimuli

Training Stimuli

TABLE 3: TRAINING SIMILAR STIMULI

Meigh (2017) Stimuli	Syllable Stress	Similar Training Stimuli
Training Set	2	/te**næ**rok/
Training Set	1	/**kæ**θotæs/
Training Set	1	/**sæ**θodæk/
Training Set	1	/**zo**tenav/
Training Set	2	/za**ʃɔ**dʒəz/
Transfer Set 1	1	/**næ**terok/
Transfer Set 1	2	/θo**kæ**tæs/
Transfer Set 1	2	/θo**sæ**dæk/
Transfer Set 1	2	/te**zo**nav/
Transfer Set 1	1	/**ʃɔ**zadʒəz/

TABLE 4: TRAINING DISSIMILAR STIMULI

Meigh (2017) Stimuli	Syllable Stress	Dissimilar Training Stimuli
Transfer Set 2	1	/**ʃɔ**dʒəzɔd/
Transfer Set 2	1	/**vu**zæʃɔm/
Transfer Set 2	1	/**fo**zæʃɔd/
Transfer Set 2	1	/**ko**zæʃɔm/
Transfer Set 2	2	/ra**sæ**θon/
Transfer Set 3	2	/gi**bɪ**ðɪb/
Transfer Set 3	2	/ʒi**bʊ**tʃeð/
Transfer Set 3	1	/**tʃe**ðugʊʒ/
Transfer Set 3	1	/**ʒʊ**gijub/
Transfer Set 3	2	/gʊ**gi**ðʊtʃ/

TABLE 5: SIMILAR TRANSFER STIMULI

Meigh (2017) Stimuli	Syllable Stress	Similar Transfer Stimuli
Training Set	2	/zæ**ʃɔ**dʒəθ/
Training Set	2	/dʒə**zɔ**zæk/
Training Set	2	/zæ**nɔ**dʒəθ/
Training Set	2	/dʒʌ**nɔ**zæk/
Training Set	1	/**θʌ**rasæθ/
Transfer Set 1	1	/**ʃɔ**zædʒəθ/
Transfer Set 1	1	/**zɔ**dʒəzæk/
Transfer Set 1	1	/**nɔ**zædʒəθ/
Transfer Set 1	1	/**nɔ**dʒʌzæk/
Transfer Set 1	2	/ra**θʌ**sæθ/

TABLE 6: DISSIMILAR TRANSFER STIMULI

Meigh (2017) Stimuli	Syllable Stress	Dissimilar Transfer Stimuli
Transfer Set 2	1	/**næ**θodæp/
Transfer Set 2	1	/**dɔ**ʤəzɔd/
Transfer Set 2	2	/sʌ**ve**næθ/
Transfer Set 2	2	/na**sæ**θoʃ/
Transfer Set 2	2	/vi**ʃə**dæk/
Transfer Set 3	1	/**bɪ**ðetʃug/
Transfer Set 3	1	/**gi**gʊðib/
Transfer Set 3	1	/**tʃe**jiwɪʒ/
Transfer Set 3	2	/bʊ**tʃi**tʃeʒ/
Transfer Set 3	2	/tʃʊ**tʃu**bɪʒ/